Marlon Leão
Volker Huckemann
Érika Borges Leão
M. Norbert Fisch
Ernesto Kuchen

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Energy efficiency of double skin façades: an approach to Brazilian climates

The heat gains and daylight transmitted through windows directly influence the building's energy demand. High performance façades, when correctly specified, produce a great potential of energy savings by using daylight efficiently and controlling heat gains and/or losses. In Brazil, the lack of natural ventilation associated with large glass areas in office buildings exhibits substandard results concerning energy efficiency. This article demonstrates an approach to highly ventilated double skin façades in Brazil, investigating the potential of natural ventilation in accordance with the local climate. Applying the Light Design and Ideal Window Area methodologies, window areas as a function of different types of high performance glass are thermally simulated in the program EnergyPlus. The simulations are run for 10 cities in Brazil, in one of those cities, Curitiba (–25° 25′ 40′′), the annual results of hourly simulations demonstrate the building energy demand as a function of window area, glass type, room ratio and size. The results concerning the energy efficiency perspective only illustrated that double skin façades could be applied for southern regions in Brazil and under certain criteria.

Energieeffizienz von doppelschaligen Fassaden: eine Annäherung an brasilianische Klimabedingungen. *Die ansteigende Temperatur und das Tageslicht, das ungehindert durch die Fenster tritt, beeinflussen den Energiehaushalt eines Gebäudes. Moderne Hochleistungsfassaden bieten bei korrekter Auslegung ein großes Potential zur Energieeinsparung, indem sie Tageslichtnutzung zulassen und solare Gewinne kontrollieren. Das Fehlen von natürlichen Belüftungsmöglichkeiten und der hohe Anteil großflächiger Glasfassaden in Bürogebäuden führen in Brasilien zu unterdurchschnittlicher Energieeffizienz. Der Beitrag beschäftigt sich mit belüfteten doppelschaligen Fassaden in Brasilien, indem das Potential von natürlicher Belüftung unter den lokalen Klimabedingungen geprüft wird. In Anlehnung an Regeln der Kunstlichtplanung und zur Ermittlung der idealen Fensterfläche werden unterschiedliche Fensterflächenanteile unter Variation der Glasqualitäten in dem Programm EnergyPlus thermisch simuliert. Die Simulationen wurden für 10 brasilianische Städte durchgeführt. Die Jahresergebnisse der stündlichen Simulationen für Curitiba (–25° 25′ 40′′) zeigen, dass der Energiebedarf des Gebäudes von der Größe der Fensterflächen, der Art der Glasscheiben sowie der Raumproportion und -größe abhängt. Die Ergebnisse bezüglich der Einschätzung der Energieeffizienz weisen ferner darauf hin, dass doppelschalige Fassaden in südlichen Regionen von Brasilien und vergleichbaren Klimaten unter bestimmten Bedingungen angewendet werden können.*

1 Introduction

In architecture, the different façade typologies and their windows have the important task of providing outside views, ventilation and daylight. They are also responsible for a significant portion of the heat gains and/or losses in buildings with **S**ingle **S**kin **F**açades (SSF) or **D**ouble **S**kin **F**açades (DSF). When shading condition, orientation, window area and glass are not correctly specified, the windows can significantly increase the buildings' energy consumption in warm as well in cold climate countries.

In Brazil, the influence of the window area on the electricity consumption of 30 SSF office buildings in Salvador city was evaluated [1]. The results indicated a correlation between the glass area and electricity consumption. The buildings with **W**indow to **W**all **R**atio (WWR) lower than 20 % presented an average electricity consumption of 96 kWh/m^2·a, the buildings with WWR higher than 40 % had their consumption increased by 51 %.

The buildings in Brazil are responsible for 42 % of the electricity consumption; 23 % in the residential sector, 11 % for office buildings and 8 % in public buildings [2]. According to several authors (Table 1), cooling and lighting account for the majority of the buildings' energy consumption.

In England, according to [11] an energy-efficient SSF building consumes 50 % less energy than an existing building. It indicates that window areas should be limited and

Table 1. End-use electricity energy consumption in Brazil
Tabelle 1. Endenergieverbräuche (Strom) in Brasilien

Source	Cities	Cooling [%]	Lighting [%]
Lomardo [3]	Rio de Janeiro	37.4	37.1
Rodas [4]	Floarianópolis	39.0	30.0
Westphal [5]	Floarianópolis	41.0	50.0
Ghisi [6]	Floarianópolis	16.0	63.0
Toledo [7]	Floarianópolis	39.4	42.2
Roméro [8]	São Paulo	42.4	14.4
Geller [9]	São Paulo	20.0	44.0
Mascarenhas [10]	Salvador	70.0	15.0

suggests WWR around 30 % to limit the energy consumption.

In Brazil, the use of large window areas can provide good daylight provision and good external view, but may also increase the energy consumption for SSF buildings with cooling systems [12]. The authors also revealed that wide rooms may not have the lowest energy consumption, and concluded that windows areas recommended in the current literature to ensure outside view are in the most part larger than the **I**deal **W**indow **A**reas (IWA) to ensure energy efficiency. The authors defined an IWA in which the energy consumption of the room is the lowest.

Other authors [13] investigated the integration of daylight with artificial lighting using the daylight simulation program ADELINE and the **B**uilding **E**nergy **S**imulation **P**rogram (BESP) TRNSYS. The authors report that an increase in the width of a room is directly associated with a decrease in artificial lighting consumption, reaching lighting savings from 50 to 80 %.

In Germany [14] considering the thermal comfort, the integration of artificial lighting with daylight and the energy efficiency, defined an IWA between 50 and 70 %. During the winter, an increase of this window area can raise the heating energy demand. In summer, with window area up to 60 % and low cooling demand, the over-heating hours are under 10 %.

The research above shows that cooling, lighting and heating consume the majority of the building's energy. The windows are responsible for significant heat gains and/or losses, also indicating that in Brazil the correct use of façade typologies, window areas, glass and shading devices represent a large energy savings potential.

The country comprises a wide range of climatic conditions across a large geographic scale and varied topography; with the largest portion of the country considered to be tropical. However, the main commercial sectors can be found in the cooler southern and southeast regions, which correspond to a heightened demand for energy. Although these commercial regions have great potential for night cooling ventilation, prohibitive factors like security, high speed wind in tall buildings and rain risks prevent its implementation. For these regions a highly ventilated DSF may be applied, improving control of the ventilation, shading systems and the integration of daylight.

2 Objective

The aim is to evaluate the applicability of highly ventilated DSF in Brazil regarding energy efficiency; taking into account the different climates of the country according to the night ventilation potential. An assessment of the annual electricity demand as a function of window areas and daylight integration is presented for office buildings with cooling system.

3 Methodology

Energy savings are generated when an artificial lighting system is integrated with the daylight that enters through the windows. An IWA may vary according to the classification of the building as either naturally ventilated or mechanically conditioned.

In the first case, the window area depends solely on energy savings achieved by reducing consumption of the lighting system. In the second case, energy savings is dependant on the energy balance between the daylight infiltration and solar heat load. This balance aims to reduce energy consumption in the lighting system and reduce the heat loads generated by it to the cooling system [12].

3.1 Prior Methodology

Using the BESP BSim, [14] studied the energy demand of one room model only. However, the authors simulated the model with three window areas, three types of high performance glass, four shading factors, four orientations, in one German city, indoor ventilation with/without night ventilation and a cooling system. The results illustrate the overheating hours, energy demand for lighting, heating and cooling systems.

In [15] the energy demand variation was studied as a function of window area applying the BESP VisualDOE for SSF buildings only. In this study the researcher simulated rooms with five ratios, ten different sizes, eleven window areas, four orientations, single clear glass, no shadow devices, seven cities in Brazil and one in England. The results showed the IWA in percentage and the increase of energy demand when the IWA is not applied. In this methodology, the IWA have wide variations when assessed with different ratios and rooms sizes. From the size perspective, larger rooms demand less energy than smaller rooms, independent of ratio. Regarding the ratio, narrow rooms (ratio 1 : 2) demand less energy than wider rooms (ratio 2 : 1), independent of size.

3.2 Applied Methodology

Using some parts of the methodologies adopted by the above mentioned authors; this article evaluates the energy efficiency of DSF office buildings for the federal capital and nine Brazilian state capitals of different latitudes (Table 2).

For the Brazilian state capital of greatest DSF potential, a more detailed study demonstrates the energy demand as a function of different room sizes and ratios. This city is Curitiba, the coldest state capital in the country; the

Table 2. Geographical coordinates of the cities
Tabelle 2. Geografische Lage der Städte

Cities	Latitude	Longitude	Altitude
Belém	–01° 27' 21''	48° 30' 16''	10 m
Manaus	–03° 06' 07''	60° 01' 30''	92 m
Fortaleza	–03° 43' 02''	38° 32' 35''	21 m
Recife	–08° 03' 14''	34° 52' 52''	4 m
Cuiabá	–15° 35' 46''	56° 05' 48''	176 m
Brasília	–15° 46' 47''	47° 55' 47''	1171 m
Rio de Janeiro	–22° 54' 10''	43° 12' 27''	2 m
São Paulo	–23° 32' 51''	46° 38' 10''	760 m
Curitiba	–25° 25' 40''	49° 16' 23''	934 m
Florianópolis	–27° 35' 48''	48° 32' 57''	3 m

city has a maritime temperate climate or oceanic climate (Cfb) [16] with average minimum and maximum temperatures ranging from 8 to 26 °C, low cooling demand and high night ventilation potential.

For these assessments, simulations are carried out by BESP EnergyPlus [17]; the models were simulated over a whole year under reference weather data files (EPW file). This program was chosen for the simulations by completing all quality requirements [18].

3.3 Model

The simulated office rooms have three ratios (Fig. 1), eighteen sizes (Table 3) and have been simulated as a function of a room index (K), well known in Light Design projects (Equation 1). This methodology, adopted in [15], has been used in the simulations of Curitiba to assess the energy demand as a function of ratio, size, orientation and glass type. The rooms are located in an intermediate floor of the building with all internal walls in adiabatic conditions (this may lead to lower cooling demand, without affecting the IWA). The primary façade consists of glass (Table 4) and light wall (Table 6), thus, the percentage of the specified window area is the effective glazed area. The DSF cavity does not vary in depth and is one meter deep with a closed ceiling and floor. The secondary façade is totally glazed with 0.5 m overhang on the façade‘s top.

$$K = WD/(W + D)h \qquad (1)$$

Where:
- K room index (non-dimensional)
- W overall width of the room [m]
- D the overall depth of the room [m]
- H mounting height between the working surface and the ceiling [m].

Table 3. Room index K and dimensions
Tabelle 3. Raumindex K und Abmessungen

K	1 : 2 W [m]	1 : 2 D [m]	1 : 1 W [m]	1 : 1 D [m]	2 : 1 W [m]	2 : 1 D [m]
0.60	1.85	3.69	2.46	2.46	3.69	1.85
0.80	2.46	4.92	3.28	3.28	4.92	2.46
1.00	3.08	6.15	4.10	4.10	6.15	3.08
1.50	4.61	9.23	6.15	6.15	9.23	4.61
3.00	9.23	18.45	12.30	12.30	18.45	9.23
5.00	15.38	30.75	20.50	20.50	30.75	15.38

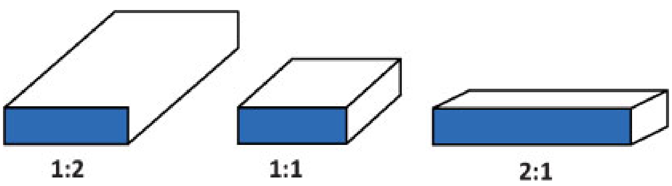

Fig. 1. Room ratio; the first number represents the façade area, and the second number represents the wall depth
Bild 1. Raumproportion; die erste Ziffer steht für die Außenwandfläche und die zweite Ziffer für die Raumtiefe

3.4 Glass

In order to represent a typical situation in office buildings with glass curtain walls in Brazil, the rooms have been simulated for the orientations north, south, east, and west with three different glass types, and glazed area ranging from 0 to 100 % at increments of 10 % and/or 20 % (Fig. 2).

The primary façade have three types of glass; (1) single clear glass, (2) double clear glass and (3) Low-E double glass, **S**olar **P**rotection **G**lass (SPG), (Table 4). The parameter study just varied the glass from the primary façade, in the secondary façade the single clear glass was held fixed.

Table 4. Simulation parameter of the glass
Tabelle 4. Simulationsparameter der Glastypen

Glass	U-value [W/m²·K]	Light T. [%]	SHGC [–]
(1) Single glass	6.12	88	0.810
(2) Double glass	2.59	81	0.761
(3) Double glass SPG	1.33	41	0.274

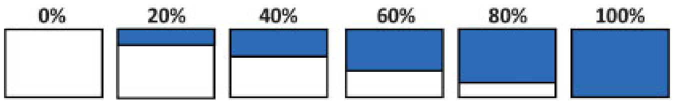

Fig. 2. Window to wall ratio [%]
Bild 2. Fensterflächenanteil [%]

3.5 Simulation Parameters

The artificial lighting system utilizes a linear dimming system that actively integrates daylight. This system works according to the internal amount of daylight illuminance levels that are reaching the working surface through the windows. The dimming system switches on/off or linearly compensates the indoor illuminance levels maintaining an illuminance of 500 Lux [19] on the work surface (0.8 m high) during working hours. The system can provide up to two sensors per zone. For rooms with a depth of 7 m or less, only one sensor was positioned in the middle axis of the room parallel to the windows. For rooms deeper than 7 m, two sensors were set. The second sensor is placed in the middle axis between the limit of the first zone (7 m deep) and the deepest back wall of the room.

In accordance with [20], the smaller the room, the higher the **L**ight **P**ower **D**ensity (LPD) necessary to provide the same illuminance level as in larger rooms (Table 5).

The room is equipped with a packaged direct expansion cooling system with mixed mode and temperature set point of 24 °C (t_a). The HVAC has auto sizing, mechanical ventilation for hygienic ventilation only (when not supplied by natural ventilation due the weather conditions) and no recovery system or heating system. The natural ventilation works on a schedule with previously adjusted **A**ir **C**hange per **H**our (ACH). The office room can reach a maximum of two ACH from 08:00 to 18:00 and six ACH from 18:00 to 08:00. The DSF cavity can have a maximum of 65 ACH during 24 hours. The ACH assumed for the simulations were taken from empirical research works [21] concerning

Table 5. Room LPD for 500 Lux
Tabelle 5. Lichtenergiedichte LPD für 500 Lux bei verschiedenen Raumindizes K

Room index K	Light power density [W/m²]
0.60	22.0
0.80	18.9
1.00	17.1
1.50	14.5
3.00	11.5
5.00	10.0

natural ventilation, where the ACH in DSF office buildings were determined using CO_2 as tracer gas applying the method of the concentration reduction. The natural ventilation operates depending on the HVAC system activity and can flow over the whole year according to the weather conditions and certain criteria.

Primary façade (room)
The natural ventilation takes place if the HVAC system is off (according to the setpoint) and the indoor air temperature is greater than the DSF cavity air temperature. This is to allow ventilation to be stopped if the temperature supplied through the cavity is too warm and could potentially heat the indoor space.

Secondary façade (DSF cavity)
As the outdoor temperature can reach negative temperatures in winter, the natural ventilation only starts with temperatures greater than 12 °C. For the other seasons or regions without winter, the ventilation works if the indoor air temperature is greater than the outdoor air temperature.

The pattern of occupation, internal gains and the HVAC system follow the typical workdays for office buildings from Monday to Friday between 08:00 and 18:00. Other input parameters and heat gains similar to the standard [22] can be seen on Table 6.

Table 6. Internal gains and input parameters
Tabelle 6. Interne Gewinne und Eingangsparameter

People	12.0 W/m² (1 person = 9 m²)
Equipment	25.5 W/m² (1 person = 230 W)
Air change rate	1.5 h^{-1}
Infiltration (primary façade)	0.3 h^{-1}
Infiltration (secondary façade)	0.5 h^{-1}
Light wall	2.00 W/m²·K

4 Results

4.1 The varying demand among the Brazilian cities

In this article 10 Brazilian cities have been assessed. Due to restricted space in this article, some detailed results are shown just for Curitiba city. The results in this paper are always presented as total end electricity energy demand for lighting and cooling in kWh/m²·a in relation to gross net area. The simulated cooling demand was weighted by a performance coefficient of 2.5. The office equipments are taken into account during the simulations as internal gains only and their electricity demand is not included in the results.

Brazil has a vast territorial expanse; as a result the Brazilian cities represent large difference in energy demand as a function of latitude. Figure 3 shows the simulation results for north orientation, using single glass (1). As the graph illustrates, even cities from warmer climate regions, such as Recife, display almost linear increases in energy demand when experimenting with WWR greater than 40 %. The cities located in southern regions have a slight tendency for greater WWR in comparison to northern regions.

In extreme latitudes, there is a great difference in energy demand; the state capitals of southern regions need almost one third of the energy required in the capitals in northern regions e.g. Curitiba and Recife. However cities on the same latitude e.g. Cuiabá and Brasília also have significant differences (Table 7), in this case, due to the higher altitude of the Brazilian federal capital.

Table 7. Comparision of different cities by 40 % WWR
Tabelle 7. Städtevergleich bei 40 % WWR

Cities	Electricity demand [kWh/m²·a]	Difference [%]
extreme latitudes		
Curitiba (–25° 25’ 40’’)	27.2	+162.5
Recife (–08° 03’ 14’’)	71.4	
equal latitudes		
Brasília (–15° 46’ 47’’)	43.4	+56.9
Cuiabá (–15° 35’ 46’’)	68.1	

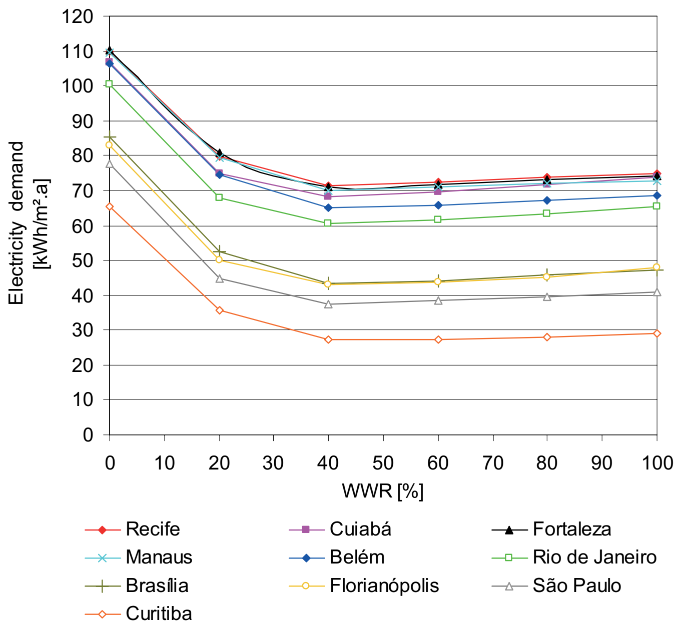

Fig. 3. Simulation results for energy demand in various cities of Brazil: north façade; ratio 1 : 2; K = 1.0; U_{Glass} = 6.1 W/m²·K
Bild 3. Simulationsergebnisse für den Energieverbrauch in verschiedenen Städten Brasiliens: Nordfassade, Raumproportion 1 : 2; K = 1,0; U_{Glas} = 6,1 W/m²·K

4.2 Comparing Double Skin Façades (DSF) and Single Skin Façades (SSF)

Regarding the energy efficiency assessment between DSF and SSF, two cities with extremely different energy demands have been considered (Curitiba and Recife). The results are compared and discussed regarding ventilation potential, IWA and façade typology (Fig. 4).

Concerning the potential of the natural ventilation, the dashed line presents the SSF without natural ventilation during off-hours and shows that warm cities like Recife have little potential for natural ventilation. However, cities with mild climates like Curitiba present large potential for natural ventilation; in addition the SSF without natural ventilation during off-hours demand twice as much energy as naturally ventilated façades, especially for large WWR.

A hypothetical and unlikely naturally ventilated SSF in Brazil is shown only to provide comparable conditions with a real naturally ventilated DSF in regards to the IWA and façade typology. Applying the IWA or lesser window area, the SSF in Curitiba is slightly more energy efficient than DSF with the advantage of lower initial investments and maintenance costs. On the other hand, the DSF allows for both cities greater WWR with less energy impact when compared to SSF. We supposed this may happen mainly due the lower SHGC values by adding the second glass layer (convective process inside the cavity), however, with higher light transmission when compared with SSF glass of same SHGC value. This supposition will be further investigated.

The designs of curtain wall buildings in Brazil normally present no shading devices to keep the aesthetic of the building and the transparent concept of the glass. The night, holiday and weekend ventilation in curtain wall business buildings are rarely applied and there are several reasons such as: security problems, high speed wind in skyscrapers and rain risk. For those reasons it is interesting to study the application of highly ventilated DSF, where shading devices can be installed without devaluing the aesthetic. The maintenance platform between the floors may also be applied for these reasons. A suitable shading device and an optimal ventilation strategy are the only points concerning energy efficiency where the application of DSF could be justified. However the DSF has real advantages in southern Brazil, where the night, holiday and weekend ventilation opportunities present immense potential, whereas in north Brazil this is absent.

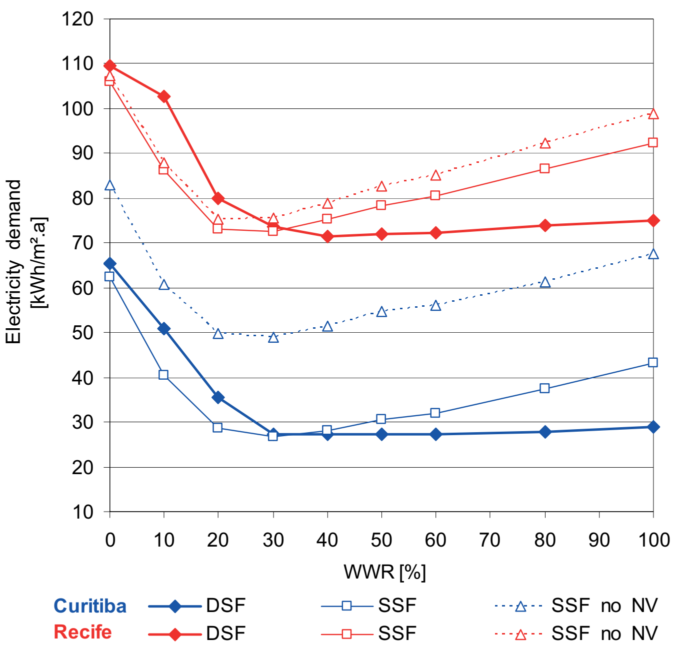

Fig. 4. Simulation results for energy demand comparing double skin façades (DSF) and single skin façades (SSF) in Curitiba and Recife: north façade; ratio 1 : 2; K = 1.0; U_{Glass} = 6.1 W/m²·K
Bild 4. Simulationsergebnisse für den Energieverbrauch im Vergleich von Doppelfassaden (DSF) und Einfachfassaden (SSF) in Curitiba and Recife: Nordfassade, Raumproportion 1 : 2; K = 1,0; U_{Glas} = 6,1 W/m²·K

4.3 DSF results for Curitiba City

The simulation results for city of Curitiba presents the four main orientations, three glass types, percentage of WWR and room sizes. Brazil is located in the southern hemisphere, and consequently should present lower energy demand in summer for this orientation. The glass is changed in the primary façade only; the secondary façade is always simulated with single clear glass (1) and 100 % WWR.

No significant differences were noted between glass (1) and (2), however in the total energy balance, which considers lighting and cooling, glass (1) is slightly better. The highly insulated glass (3), in relation to the glass (1) and (2), is the most inefficient for all orientations demanding ~9 kWh/m²·a more energy (Fig. 5).

Glass (3) presents better thermo-physical parameters than glass (1); however, it demands more energy. With shading devices and natural ventilation applied, the reason is not the decrease in the heat dissipation capacity through the glass but rather the need for more lighting due to the lower light transmission (41 %), (Fig. 6). This

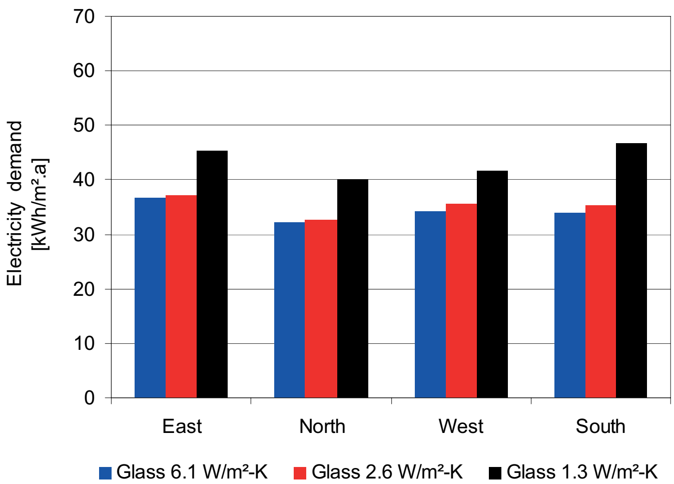

Fig. 5. Simulation results for energy demand comparing three glass types for the primary façade of double skin façades (DSF), in Curitiba: ratio 1 : 2; K = 1.0; average from 0 to 100 % WWR
Bild 5. Simulationsergebnisse für den Energieverbrauch im Vergleich von drei Außenscheiben in Doppelfassaden (DSF) in Curitiba: Raumproportion 1 : 2; K = 1,0; Durchschnitt von 0 bis 100 % Fensterflächenanteil

can also be seen in the south orientation where the difference reached 13 $kWh/m^2 \cdot a$ (Fig. 5). Regarding the cooling demand both glass types present similar results, however the glass show a small reversal point after the 50 % WWR, where the glass (3) SPG displays better results (Fig. 6).

The two following Figures 7 and 8 show the energy demand as a function of different ratios (see Fig. 1) and room sizes (see Table 3). As can be seen in Figures 7 and 8, same sized rooms with larger façades (2 : 1) tend to have smaller IWA. For small rooms (Fig. 7) with WWR greater than the IWA the energy demand increases rapidly due the solar heating gains.

Large rooms have greater IWA than small rooms; this is because of lower cooling loads in the back zones, even when the back zones are fully illuminated by artificial lighting.

Figure 9 illustrates this relationship: the larger the room, the greater the IWA; this fact was also observed for other ratios and cities. When the WWR increases, the energy demands of smaller rooms increase slightly, whereas it decreases in larger rooms. This happens because the solar gains through the glass in relation to volume are higher (index A/V) and the LPD in smaller rooms are higher to keep an illuminance of 500 Lux on the working surface [20].

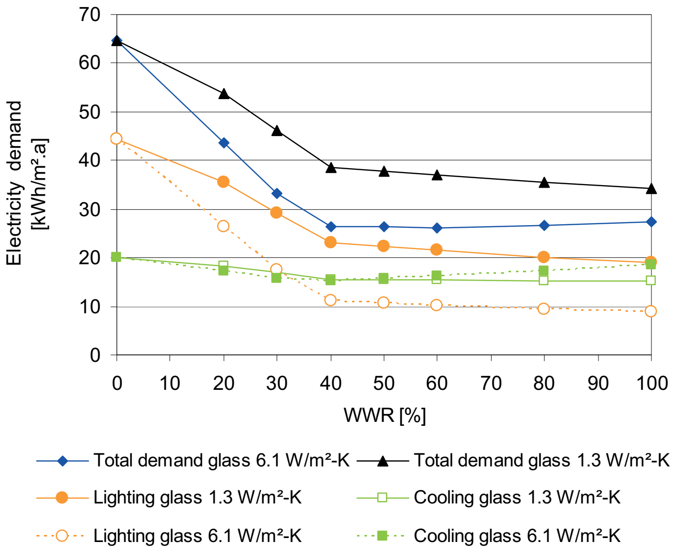

Fig. 6. Simulation results for cooling and lighting energy demand comparing two glass types for the primary façade of double skin façades (DSF), in Curitiba: ratio 1 : 2; K = 1.0; average from four orientations
Bild 6. Simulationsergebnisse für den Kühl- und Beleuchtungsenergieverbrauch im Vergleich von zwei Glastypen in Doppelfassaden (DSF) in Curitiba: Raumproportion 1 : 2; K = 1,0; Durchschnitt, Mittelwert über vier Orientierungen

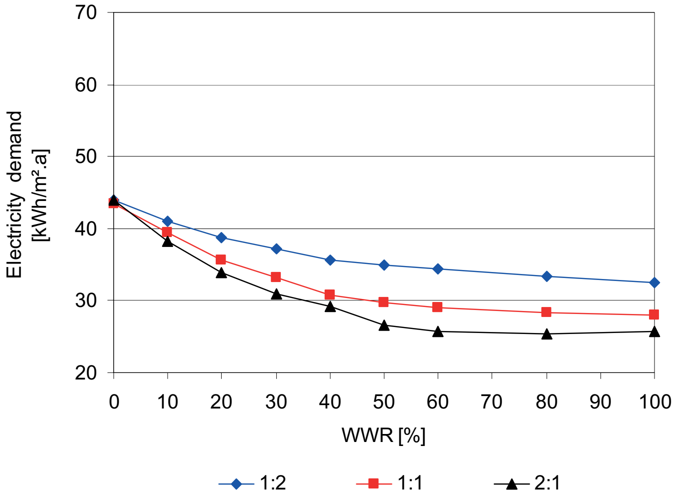

Fig. 8. Simulation results for energy demand as function of the window to wall ratio (WWR), in Curitiba: north; K = 5.0; U_{Glass} = 6.1 $W/m^2 \cdot K$
Bild 8. Simulationsergebnisse für den Energieverbrauch als Funktion des Fensterflächenanteils (WWR) in Curitiba: Nord; K = 5,0; U_{Glas} = 6,1 $W/m^2 \cdot K$

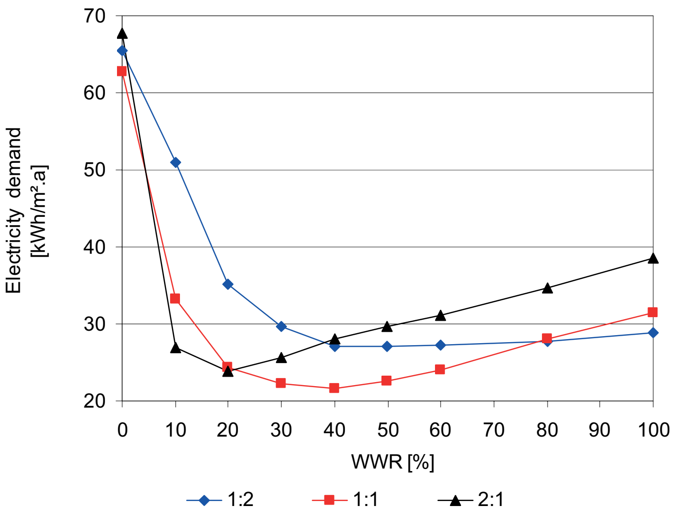

Fig. 7. Simulation results for energy demand as function of the window to wall ratio (WWR), in Curitiba: north; K = 1.0; U_{Glass} = 6.1 $W/m^2 \cdot K$
Bild 7. Simulationsergebnisse für den Energieverbrauch in Abhängigkeit vom Fensterflächenanteil (WWR) in Curitiba: Nord; K = 1,0; U_{Glas} = 6,1 $W/m^2 \cdot K$

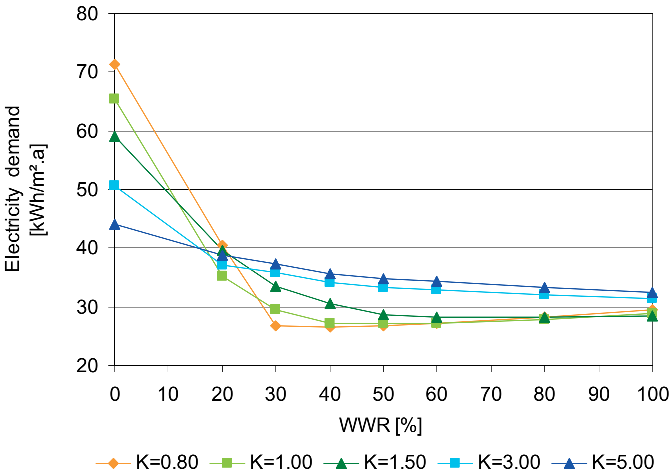

Fig. 9. Simulation results for energy demand as function of the window to wall ratio (WWR) for various K values (room index), in Curitiba: north; ratio 1 : 2; U_{Glass} = 6.1 $W/m^2 \cdot K$
Bild 9. Simulationsergebnisse für den Energieverbrauch als Funktion des Fensterflächenanteils (WWR) für verschiedene K-Werte (Raumindex) in Curitiba: Nord; Raumproportion 1 : 2; U_{Glas} = 6,1 $W/m^2 \cdot K$

5 Conclusion

This article assessed the energy demand of 10 Brazilian cities through the application of EnergyPlus program. An energy comparison between DSF and SSF evaluated the potential of natural ventilation between northern and southern regions. Moreover, the influences of the IWA, room ratio and size on the electricity demand were analyzed. This paper disregards the holistic perspective, which must not only address the energy optimization, but also the visual comfort, thermal comfort, acoustic comfort and air quality as well. Accordingly, the following can be confirmed:

Despite the completely different climate conditions of the cities, the IWA curves for DSF buildings did not move as much as SSF. However, the cities located in southern regions have a slight tendency to have greater IWA. Still, more detailed descriptions, as shown for Curitiba, should be carried out.

The northern regions of Brazil do not have an appropriate climate for DSF applications. The southern regions are better candidates for DSF. Cities located in center Brazil at high altitudes and with greater temperature amplitude may have potential (e.g. Brasília), but require further study. In the southern regions, the DSF is justified due to the natural ventilation potential. The DSF in Curitiba, when compared to SSF without natural ventilation during the off-hours, demands an average of half the energy. When comparing naturally ventilated DSF and SSF (the latter unlikely), the DSF allows greater WWR with lower impact on the energy demand.

Even in the coldest state capital in Brazil (Curitiba), the use of SPG glass can increase the energy demand. The results for this glass illustrated much lower heating gains in the room and no problems due to the decreased heat dissipation capacity through the glass when shading devices and natural ventilation are applied. However, the higher electricity demand for lighting, due to the lower light transmission (41 %), compromises the performance of the glass in the total energy balance.

In relation to DSF and the energy demand as a function of WWR, room ratio, size and the models here evaluated, it can be stated that: independent of room size, the larger the façade, the lower the IWA; and independent of ratio, the smaller the room area, the lower the IWA.

The results presented in this article only concern the specific assessed DSF model (or cell) and must not be taken as a guideline. In addition, Brazil is a large country with many climates and sub-climates, just a few examples have been demonstrated here. The simulation of DSF is a very complex physical phenomenon. It involves mainly optical, thermodynamic and fluid dynamic processes and no single simulation tool is able to handle all these process very efficiently [23]. A larger DSF parameter study for Brazil with BESP and CFD programs, taking into consideration the cost/benefit, payback and building life-cycle cost is under development and is still to be published.

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Authors:
M.Sc. Arch. Marlon Leão, Dipl.-Ing. Arch. Volker Huckemann,
M.Sc. Arch. Érika Borges Leão, Univ.-Prof. Dr.-Ing. M. Norbert Fisch,
Dr.-Ing. Ernesto Kuchen
All:
IGS – Institut für Gebäude- und Solartechnik, School of Architecture at the Technical University of Brunswick, Germany